

## Tube Systems and a Fabrication Process for These

The present invention relates to tube Systems of the type described in greater detail in Patent Claim 1, and to a , fabrication process for such tube Systems. Microtube

Systems of this kind are known in vacuum microelectronic technology [Brodie, J., J. Muray *The Physics of micro and nano-fabrication*, Plenum Press, NY (1992)]

Such tube Systems are provided with lithographically fabricated cathodes that are known as Spindt cathodes. These cathodes are fabricated by complex lithographic processes in a multi-layer structure using optical or corpuscular beam lithography, with a partially self-

15 adjusting procedure. The field emission cathode can be etched from Silicon, coated with heavy metals, or built up from metals by vapor deposition. The reproduceability of the fabrication process is so small, however, that it is always necessary to use cathodes arranged in an array  
20 in order to ensure the emittance of the cathode and achieve the required low internal resistance (transconductance) of the tubes.

Because of the large number of cathodes arranged in  
25 planes, the parasitic capacity of the circuit increases and limits the Systems to Operation at a few

GHz, as is described in the reference quoted above  
[Brodie, J., J. Muray *The Physics of micro and nano-*  
*fabrication*, Plenum Press, NY (1992)].

It is the task of the present invention to create tube  
Systems that are suitable for considerably higher  
frequencies and to describe a practical fabrication  
process for doing this.

The present invention has solved the first part of this  
problem with a System as described in the preamble to  
Patent Claim 1.

15 An advantageous development to this is described in the  
preamble to Patent Claim 2.

The second part of this problem has been solved by a  
fabrication process as set out in the preamble to Patent  
Claim 3.

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An advantageous development of this process is described  
in the preamble to Patent Claim 4.

25 The present invention, with its numerous possible  
variations and the variations of its effects, is

described in greater detail in the embodiments that follow. The drawings appended hereto show the following:

Figure 1: The structural principles of diodes, triodes,

5 and deflecting tetrodes with THz switching characteristics;

Figure 2: Above: triodes consisting of cathode, emitter, and anode. Below: triodes consisting of a plurality of

10 cathodes, grid, and anode that amplify the emission grid signal;

Figure 3: Micro-triodes with potential flow, cathode 0V, grid 50V, anode 60V;

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Figure 4: Micro-pentode with field emitter-cathode K, grids G1 to G3, and anode A with potentials;

Figure 5: Micro-tubes constructed with the help of  
20 electron-beam induced deposition and computer control in a scanning electron microscope. Above: plan view, below: side view of two tubes;

Figure 6: Oblique view of two micro-tube constructions of  
25 nano-crystalline material that contains platinum.

The tube systems that have been described consist of one or more field emission or field ionization cathodes for electrons or ions, which are connected in parallel; a grid electrode with one or more annular apertures; and  
5 one or more anodes. All the electrodes are built up with the help of corpuscular beam lithography with induced deposition, either in sequence or simultaneously, on a planar conductor wiring structure that supplies the voltages. The spacing between the electrodes is selected  
10 so as to be small enough that in the centre only a mean-free path length of the molecules at normal pressure fits between the emitter and the anode electrode. At normal pressure in air, this section is approximately 0.5  $\mu\text{m}$  in size.

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In order to avoid electrical flashovers because of the growth of molecular chains, which occur above  $10^6$  V/cm, the electrodes that conduct the voltage are close together, and the conductor tracks are spaced well apart.

20 Diameters of 0.1/mm and spaces  $> 0.5/\text{m}$ . are sufficient to keep the field strengths in the tubes below the limits that are required for continuous operation at the operating voltage of  $< 50\text{V}$ .

25 Tubes of this kind need no vacuum, or only a very slight one (1 Torr), for continuous operation and for this

reason they are classified not as miniaturized microelectronic tubes, but rather miniaturized multi-electrode tubes. The tubes can be operated with different polarities, for electrons are ionized at  $2-10^7$  V/cm and 5 water at  $10^7$  V/cm. These field strengths are achieved if etched monocrystals are not used as field emitters or field ionizers, rather if the nanocrystalline composite materials that result from electron-beam or ion-beam induced deposition are used.

10

The materials are nanocrystalline and can be installed as super-tips on blunt, prefabricated tips or electrodes. Because of their nanocrystalline structure, these super-tips emit or ionize this absorbed water or other gases even at the cited field strengths that have been reached at the low voltages below 50V, if the cathode-anode spacing is smaller than the average free path length of the gases at normal pressure. Tubes of this type have very small capacities, and have an electron flight time

20 of less than 1 ps, or  $< 40$  psec for the ions. This means that these tubes can be used successfully in the highest frequency technology as electronic building blocks. Because of the very small space requirement of less than a few  $\mu\text{m}^2$ , several of these tubes can be  
25 connected together in the immediate vicinity of set-up circuits. Resistors with very small capacities, and

small capacities and inductivity can also be fabricated in the  $\mu\text{m}$  range with corpuscular beam induced deposition and then used in circuits, so that the integrated tube electronics can also be used in GHz applications.

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Diodes, triodes, tetrodes, pentodes, miniaturized accelerators and filters and other corpuscular beam-optical arrangements can also be built using this technology. Tips as field emission cathodes for electron emitters and for ion emitters can be used in other pre-fabricated circuits and tubes, so that the required operating voltage can be greatly reduced.

Using electron beam induced deposition, nanocrystalline composite material can be built up with nanometer precision to form

15      nanoelectronics structural units and circuits in a proposed wiring plane.

With this new type of technology, which uses new materials and computer control and automation, it is

20      possible to achieve new, and previously unattained, performance.

Some preferred embodiments of tube systems which are mounted on an insulating medium, on printed conductor

25      structures produced by using planar technology, by lithography, field emission cathodes with passive current

stabilizing resistors and to which at least one anode to which one or more wires is allocated, are

- a diode connected as an field electron emitter and driven by electrons;
- a diode connected as an ion emitter and driven with  $H_3O^+$  ions, (since all surfaces are covered with water and for this reason field ionization takes place at above  $10^7$  V/cm and determines the transconductance of the tube),
- a conventional triode, which can be driven with ions or electrons in which, apart from the cathode and anode, a grid in the form of one or more apertures or in the form of two rods without upper and lower limits of the field, is connected between the two electrodes;
- a tetrode or pentode, in which the first grid is followed by a plurality of grids and partial grids, and which can be incorporated separated by two potential supply lines and so permit rapid switching between two opposing and insulated anodes.

All of these tubes can be operated in a moderate vacuum of one Torr, so that the mean free path length of the electrons or ions in the gas at this pressure is so

adjusted that the tubes are functional through the tube dimensions.

The tubes can be hermetically encapsulated in an evacuated vessel and the electrical lines can pass through the capsule as thin-film lines. The electrical lines can also pass through the walls of the capsules as through-feed lines, in bores that are filled with insulating material.

10           A plurality of tubes, and even whole circuits, can be assembled in a large vacuum space that is filled with suitable pressure and gas or water of sufficient partial pressure, and hermetically sealed, and the hollow space

15           can be kept constantly at a vacuum with an installed getter material, as is usual in tube technology.

          A plurality of electron or ion emitters can be connected in parallel in order to achieve a low internal tube  
20           resistance and to increase the emission flow.

The size of the resistors that are used for passive flow regulation of the emitters and which are incorporated ahead of the electron or ion emitters can be so

25           configured that the field strength variation in the tubes



is evened out and even current emission from the individual cathodes is achieved.

Using corpuscular beam-induced deposition it is possible to build up conductive and insulating wires in two and in three dimensions. The wire diameters are approximately  $0.1\mu\text{m}$  and their lengths can be up to  $10\mu\text{m}$ . The wires can withstand current densities of  $2\text{ MA/cm}^2$ . This value is eight times 10 ..higher than the value for aluminum ( $250,000\text{ A/cm}^2$ ), for example. Field emission from the wire tips is possible at approximately 15 times lower internal resistance per emitter than is the case with conventional field emitters used in vacuum microelectronics. Using this technology, it is possible to assemble field emitter

15 electron sources with built-in current stabilizer resistors. When this is done, each tip works independently and under control and is stabilized passively with respect to its emission current. This reduces the demand for redundancy at the tips in the tubes or in the emitters that are arranged in parallel.

The wires end in a very fine tip with radii of less than five nanometers, but with nanometer-size crystals that extend from the tip and thus bring about a field amplification. This results in a greatly reduced extraction voltage for the field electron current. The

resistance of the deposited material can be adjusted within the range of five orders of magnitude by way of the deposition conditions. Three-dimensional structures are fabricated using computer-controlled deposition, and

5       these serve as electrodes for micro tubes and tube systems that generate individual beams or which can be fabricated many times adjacent to each other. Thus, a technique has been found with which multiple electron beams can be produced on lithographic circuits and circuit boards, which can then be used as production means for deposition structures. This means that the production technique has been found with which micro tubes, dynatron oscillators and rapid amplifying circuits or rapid digital storage that can be erased with 100 GHz can be produced using

15       parallel fabrication technology.

Because of the fineness of the definition of the material generation during computer-controlled corpuscular beam induced deposition, it is possible to  
20 write new types of tube elements, differential amplifiers and circuits directly, without using semiconductor materials. Because of the smallness and the nanometer precision at higher frequencies, these circuits can be operated at higher frequencies than can be achieved using  
25 conventional tubes. The fabrication technique for

electronic circuits has been greatly simplified, and packing density has been considerably increased.

As a first example of an application, Figure 1 shows the assembly principles for a diode, a triode, and a  
5 deflecting tetrode with THz switching properties. In the case of the deflecting tetrode, the amplification factor and a superimposed circuit can be realized on two anodes; this makes particularly stable operation possible.

The upper part of Figure 2 shows a triode made up from a cathode, emitter, and anode; the lower part of Figure 2 shows a triode made up from a plurality of cathodes, a grid, and an anode to increase the emission flow and

15 reduce transconductance.

Figure 3 shows a micro-triode with the potential curve. The cathode is at 0 V, the grid is at 15 V and the anode at 60 V. Because of the plurality of grids that are

20 incorporated between cathode and anode, multi electrode tubes, accelerators and retarders, and other tubes can be constructed.

Figure 4 shows a micro pentode consisting of a field

25 emitter-cathode K, grids G1 to G3, and an anode A with potentials.

Triode assemblies that have already been realized are shown in Figure 5. This shows the construction of two micro tubes. The tubes are built up in non-optimized form with the help of electron beam induced deposition and  
5 computer control in a scanning electron microscope. The two tubes are shown above in plan view and below this as viewed from the side.

Figure 6 is an oblique view of two micro tube assemblies  
10 that are of nanocrystalline material that contains platinum. The drawing shows the technique for the structuring with additive lithography.

Figures 5 and 6 show the first design for the arrangement  
15 consisting of the existing "FEGBOGEN" and "STACIR" macros with the help of the VIDAS radiation control on the JSM 840 F. The anode wires are grown in 1 minute. The height of the tip position for the grid rectangle can be still be adjusted by varying the parameters. An almost  
20 round mesh can be produced by varying the parameters in the "STACIR" macro.

By using suitable deposition conditions, the small pins  
25 that hold the tip can be configured as a low-resistance heating element and the shaft that bears the tip can be

configured as a high-resistance passive stabilizing resistor. By heating the tip, gas that has been absorbed can be desorbed and the emission can be stabilized during operation. This can also be achieved by continuous  
5 heating or occasional "flashing," i.e., short periods of heating the tip, the tip being cleaned in the conventional manner by this process.

The performance data that can be achieved with the triodes can be determined from the following data. The field emitter tube works at 150 micro amperes emission current at an accelerator voltage  $U_{extr} < 10V$ . Then, the transconductance  $R_i > 15\text{microSIEMENS}$ . Conventional field  
( emitters operate at 1 - 2 micro SIEMENS! . The field

15 emission tube can be switched in various ways:

1. Application of a switching voltage to the extraction voltage at the tip of  $-U_{ext}$ . The extractor and the anode are then at 0V or positive.

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2. Application of the switching voltage to the extractor at  $+U_{extr}$ . The tip is then at 0V.

3. Deflection of the beam with deflector plates  $U_p < 10V$   
25 the extractor grid is divided into two and different voltages are applied to the two halves. Then the beam is

deflected onto the two separately constructed anodes  
(switching tubes with a permanent beam).

The memory capacity that has to be charged is:

$$C = \epsilon_0 \epsilon_r (F / d) = 8.86 \cdot 10^{-12} - 1 - (0.2 \cdot 10^{-6})^2 \cdot 10^{-6} \text{As/V} = 3.5 \cdot 10^{-18} \text{F}$$

5

At a rod diameter of 0.2  $\mu\text{m}$  and a length of 1  $\mu\text{m}$  at an interval of 1  $\mu\text{m}$  and with the dielectric of vacuum or air  $\epsilon_r = 1$ , the capacity has the value of 3.5 atto Farad. In order to charge this capacity to 5 Volts deflection voltage a charge of  $Q = C \cdot U = 1.6 \cdot 10^{-17} \text{As} = 100 \text{e} = 100$  electrons! is necessary. This charge can be raised in one psec (1 THz) with a current of 16  $\mu\text{A}$ . The statistical error is then 10 percent or  $S/N = 10$  (corresponding to the signal-to-noise ratio).

15 The switching with 0.1 ps can be effected at 160  $\mu\text{A}$  discharge current (voltage pulse on the extractor tube). Thus, these tubes that are built without semiconductor materials are superior to the circuits assembled from III/V-or II/VI semiconductors with respect to their  
20 switching speed.

## Patent Claims

1. Tube systems consisting of multi electrode arrangements with any combination of electrodes, connections, and functions, that are encapsulated in an evacuated vessel that is hermetically sealed, characterized in the way that the electrodes and the interval between them are selected so as to be so small that in the middle only a median free track length of the molecules at normal pressure fits between the emitter and anode electrodes; in that the electrodes that conduct the voltage are made so as to be close together and the conductor tracks are made so as to be far apart, the cathodes/emitters are formed in needle form and are nano-crystalline or configured as super tips on blunt prefabricated tips or electrodes; and in that the evacuated vessel contains residual gases of particularly defined types in particularly defined pressure ranges.

2. A tube system as defined in Claim 1, characterized in a way that tubes systems of different operating types are connected to each other by different additions such as grids, anodes, and other structural elements that are amenable to integration, as well as by separation into sections of the vessels that are connected by passageways.





3. A fabrication process for tube systems, characterized in that nanocrystalline material is assembled on an insulating medium that is prefabricated in planar technology using lithography by means of computer controlled corpuscular-beam induced deposition, in part simultaneously and in part in sequential steps, with nanometer precision, to form electronic assembly groups and circuits in a pre-determined wiring plane, whilst at the same time the operating type of the tubes is determined by the type and pressure of the residual gasses.

4. A fabrication process for tube systems as defined in Claim 3, characterized in that tubes are used as ion emitters and operated with  $H_3O^+$  ions, in that residual gasses that are un-dried or deliberately moistened are used from a source, until at field strengths of over  $10^7$  Volt/cm fieldionisation sets in and determines the transconductance of the tubes.

1. Tube Systems and a Fabrication Process for These.

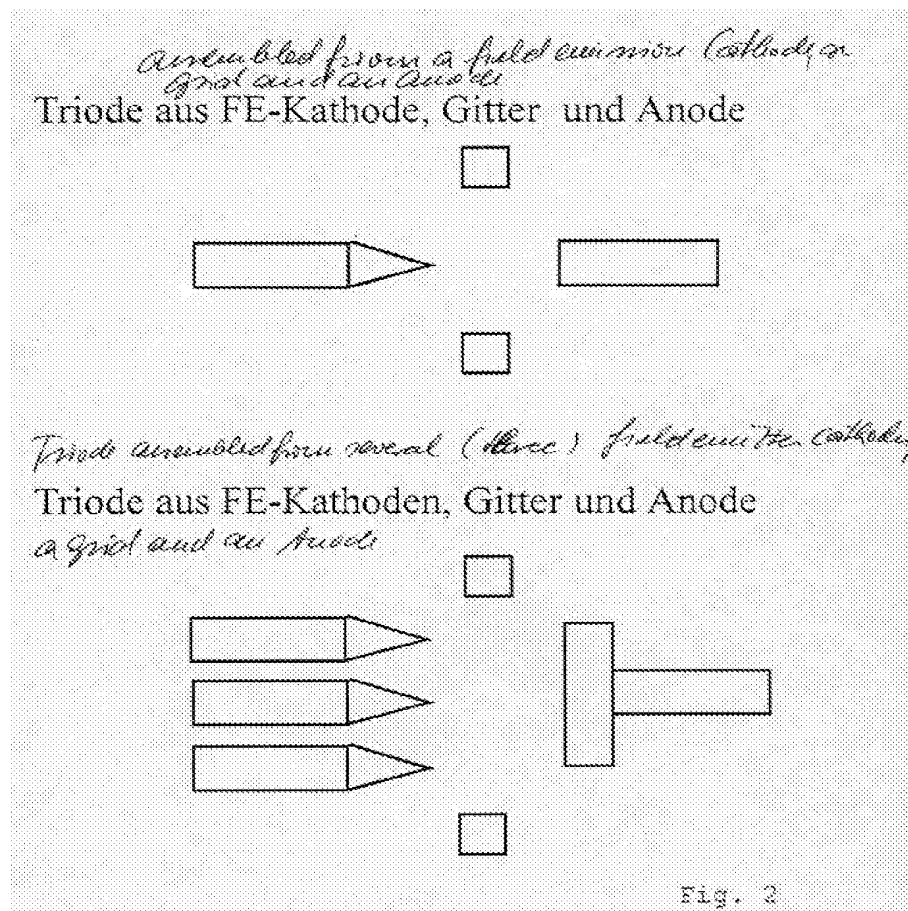
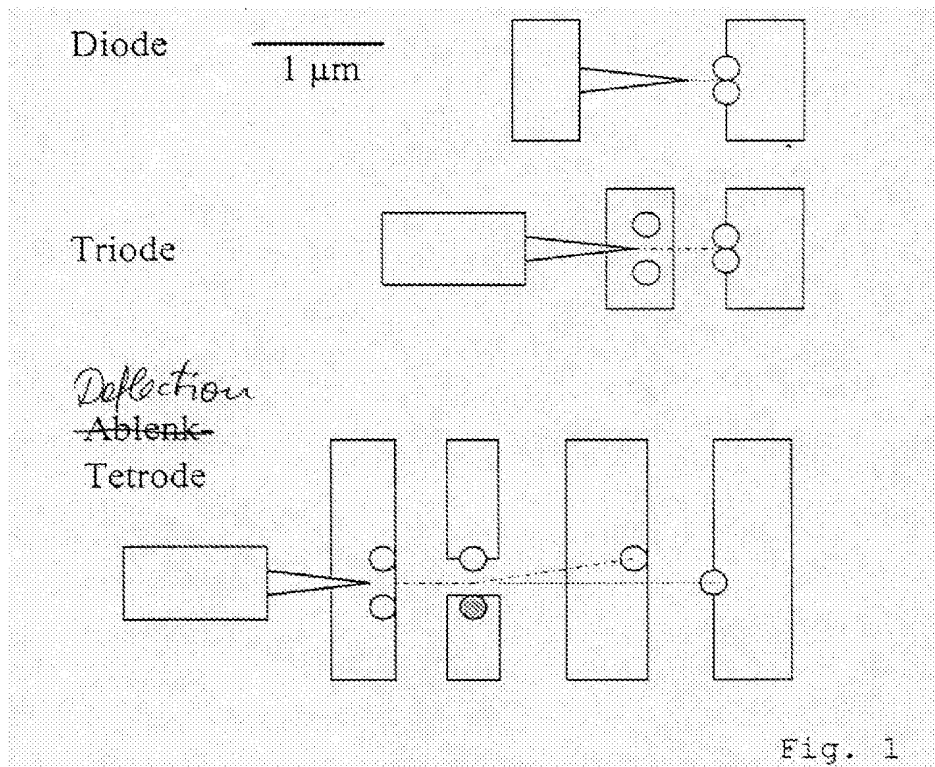
2 Abstract

2.1 In known tube systems, the upper limiting frequency and the noise characteristics are limited by the known process for fabricating miniaturized multi electron tubes such as diodes, triode tubes and multi-electrode tubes.

2.2 The tube systems that are described consist of one or more field emission or field ionization cathodes for electrons or ions that are connected in parallel, a grid electrode with one or more annular openings, and one or more anodes. All the electrodes are assembled with the help of corpuscular beam lithography with induced deposition, in sequence or simultaneously on a planar conductor track structure that feeds the voltages. The interval between the electrodes is selected so as to be  
15 so small that in the middle only a mean free track length of the molecules at normal pressure fits between the emitter and anode electrode.

2.3 The possibilities for using the present invention are universal but are preferably related to high-frequency technology.

3. Figures 3.



## Micro-Triode

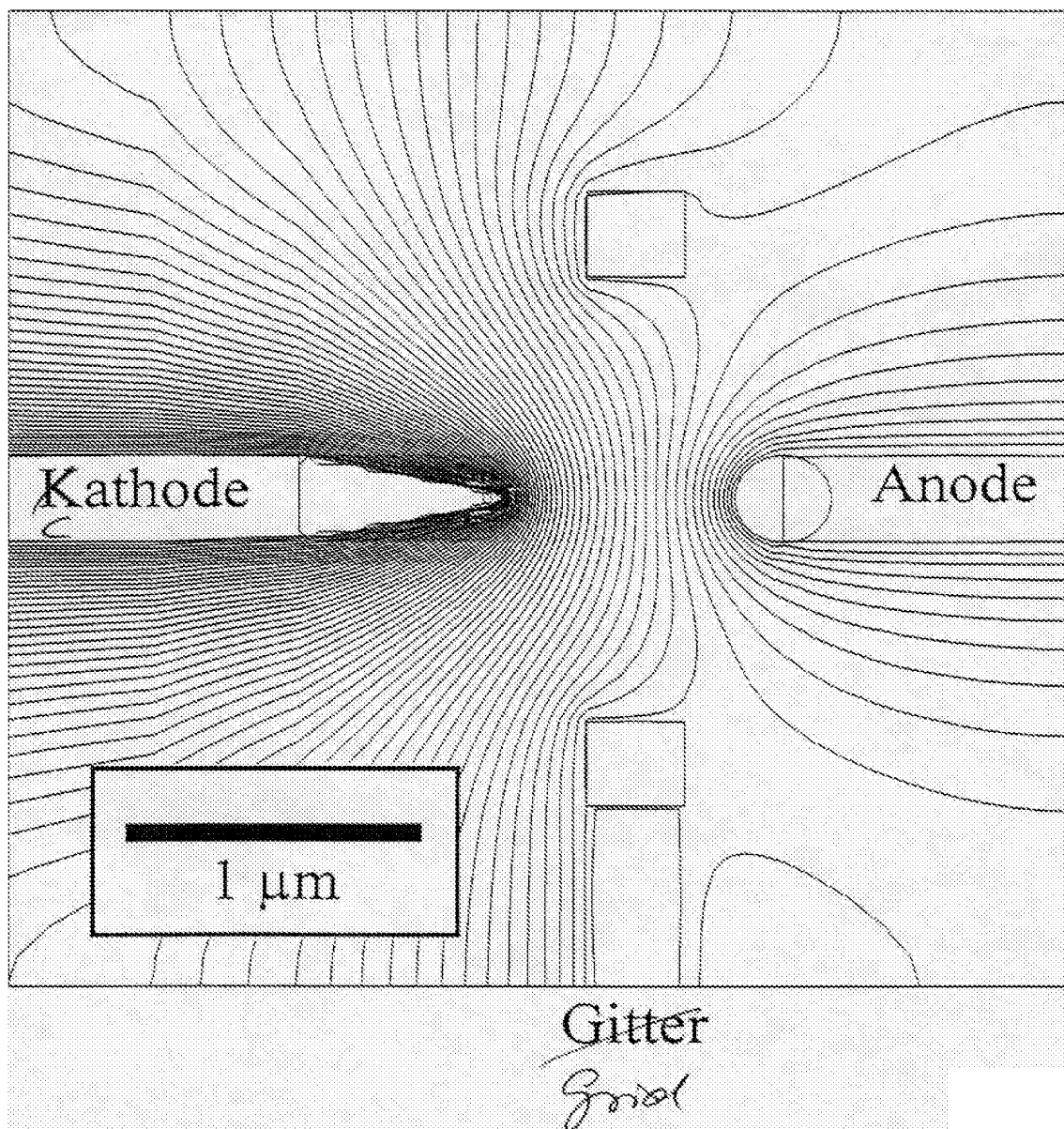


Fig. 3